CHASSIS Lubrication — Lubricate for SAFETY every 1,000 MILES

VOLUME VI • NUMBER 1 APRIL, 1942

Grease Consistency Investigations

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Presented Before 9th Annual Meeting N. L. G. I.

One of the most used tests for grease specifications and manufacturing control is consistency. Yet consistency is one of the most elusive properties when related to plasticity, leakage, temperature change and oxidation, whether checked in the container or under service conditions. Consistency is that property of a material that resists change of shape and is defined by complete flow-force relation. The consistency requirement of the grease is largely governed by the feeding appliances, service conditions and life expectancy. However, many factors, other than that expressed by the worked consistency at 77° F. (A.S.T.M. Designation D217-38T), enter into service-life hardness requirements of a grease.

Lubricating greases are mixtures of petroleum oil and some kind of soap. The soap content changes the consistency but not always in direct proportion to the percentage of soap (Figure 1) because different fats, base mineral oils, percentage of water, rates of cooling, etc., alter the final worked consistency of the finished product.

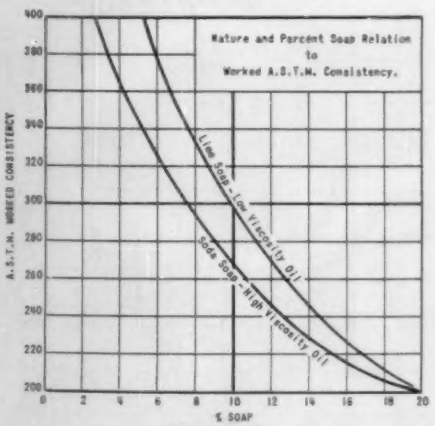
Nature and Percent Soap Relation to Worked A.S.T.M. Consistency.
Lime Soap - Low Viscosity Oil
Soda Soap - High Viscosity Oil
A.S.T.M. WORKED CONSISTENCY
% SOAP

FIGURE 1

Even after a grease is taken out of the kettle and packaged, its consistency changes. Aging (Figure 2) is a characteristic of soda soap greases. In some cases the grease should be aged five or six weeks before shipping, in order to index the consistency on final set hardness.

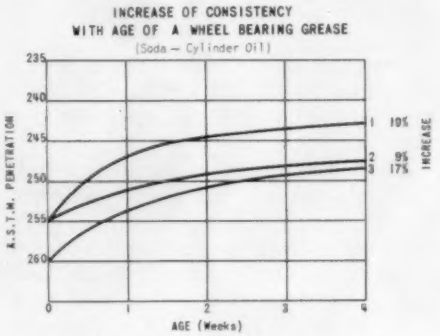

FIGURE 2

The worked consistency at room temperature (77° F.) has little bearing on that actually met with in practice, as bearing applications run much higher and lower in temperature. Therefore, the change of consistency of greases with different temperatures (Figure 3) is just as important in a grease as V. I. is in an oil. Take, for example, the N.L.G.I.* No. 3 grade cup grease (Curve 3 on Figure 3) which shows a No. 2 grade at 150° F. and a No. 4 grade at 0° F. The chassis lubricant (Curve 4 on Figure 3) is a No. 0 grade at 77° F. and a No. 3 grade at 0° F.*

Even wider variations exist: the heavy wheel bearing grease (Curve 1 on Figure 3) changes from an N.L.G.I. No. 0 to an N.L.G.I. No. 6 grade when checked at 190° F. and 0° F. respectively. This consistency change with temperature is one of the factors that relates to grease gun discharge quantities and torque retardation of anti-friction bearings.

*A classification of lubricating greases by A.S.T.M. worked consistency has been copyrighted by the National Lubricating Grease Institute, and became official on March 1. The classification follows:—

N.L.G.I. Grade	*A.S.T.M. Worked Penetration*
No. 0	355-385
No. 1	310-340
No. 2	265-295
No. 3	220-250
No. 4	175-205
No. 5	130-160
No. 6	85-115

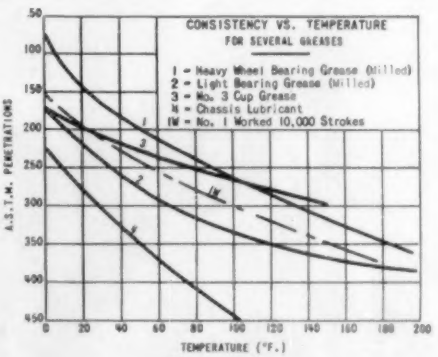
CONSISTENCY VS. TEMPERATURE
FOR SEVERAL GREASES
1 - Heavy Wheel Bearing Grease (Milled)
2 - Light Bearing Grease (Milled)
3 - No. 3 Cup Grease
4 - Chassis Lubricant
W - No. 1 Worked 10,000 Strokes
A.S.T.M. PENETRATIONS
TEMPERATURE (°F.)

FIGURE 3

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It will be noted when the heavy wheel bearing grease (Curve 1 on Figure 3) is worked 10,000 strokes in the Sinclair-Knopf motorized grease worker that it is softened, as represented by Curve 1W (Figure 3). When the motorized grease worker is carried out at different temperatures, greases

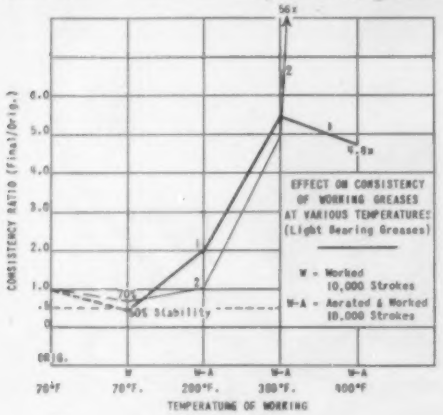

CONSISTENCY RATIO (Final/Orig.)
TEMPERATURE OF WORKING
EFFECT ON CONSISTENCY OF WORKING GREASES AT VARIOUS TEMPERATURES (Light Bearing Greases)
W - Worked 10,000 Strokes
W-A - Aerated & Worked 10,000 Strokes
50% Stability

FIGURE 4

give entirely different stability curves (Figure 4). This is expressed by their respective consistencies, after each is worked at high temperatures for 10,000 strokes in the apparatus (Figure 5). It will be noted that

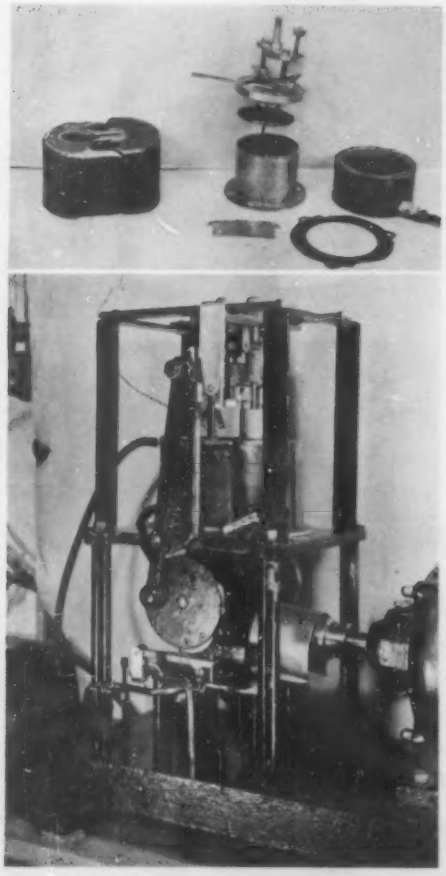


FIGURE 5

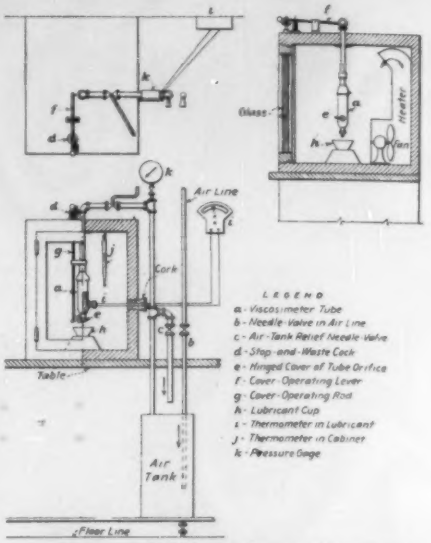
grease No. 2, when worked at 400° F. ends up with a consistency 56 times the original, due to oxidation, whereas grease No. 1 is increased only 4.8 times in hardness.

Figure 5 is a view of the motorized worker, showing the hot cup in position. At the top may be seen a cam device for opening the vent valve at top-stroke and closing same at bottom of stroke. On the crank disc may be seen a cam with follower which operates an air valve. Air is omitted at the top dead-center and cut off at mid-stroke, allowing pressure to drop before vent is closed. Pressure manometers, pressure regulators, airflow meters, and other auxiliary devices may be seen to the left. This device is used to aerate grease as it is being worked. The purpose of this is to oxidize the grease at various temperatures up to 350° F. and 400° F.

Figure 5 shows the standard cup and cover provided with packing nuts. Note that on the cover are an air inlet tube, a thermocouple tube on the axis, extending through the center of the plant, and a vent valve at the right. At the extreme right note the electric heater, and at the left an insulating cover.

It appears that this hot-worker is suitable for classifying bearing greases with regard to their stability at high temperature services.

In addition to aging, temperature-working stability and temperature-consistency changes, the pressure variation, as given by the Pressure Viscosimeter (Figure 6) is important. Pressure-Viscosity of semi-plastic and plastic greases can be measured accurately by means of the P. V. viscosimeter. This instrument is essentially a steel cylinder, provided with a standard Saybolt orifice



SINCLAIR REFINING CO. PRESSURE VISCOSIMETER

A Cylindrical Nickeled-Steel Tube, *a*, for the Lubricant Sample Is Mounted in an Insulated Cabinet Which Can Be Maintained at a Constant Temperature within a Range from —25 to +225 Deg. Fahr. The Top Cap of the Tube Communicates with a Constant-Pressure Air-Tank below the Cabinet. Needle-Valves, *b* and *c*, Control the Pressure in the Tank, and a Stop-and-Waste Cock, *d*, Enables the Operator To Apply Pressure to or Release It from the Tube *a*. A Hinged Cover, *e*, at the Bottom of the Tube Is Operated by a Lever, *f*, and a Rod, *g*, To Release Lubricant into the Lubricant Cup, *h*

FIGURE 6

and a means for applying air pressure to the sample, each type of product requiring a certain pressure to give correct viscosity readings, with average errors not to exceed 1 to 1½%. The Gardner mobilometer and the improved SIL instrument are pressure viscosimeters of a sort, but cannot read consistency as it is defined. Even though the 3 greases (Figure 6) have an N.L.G.I. No. 3 grade consistency, it will be noted, for the same 100 pounds per square inch pressure,

(Continued on Page 4)

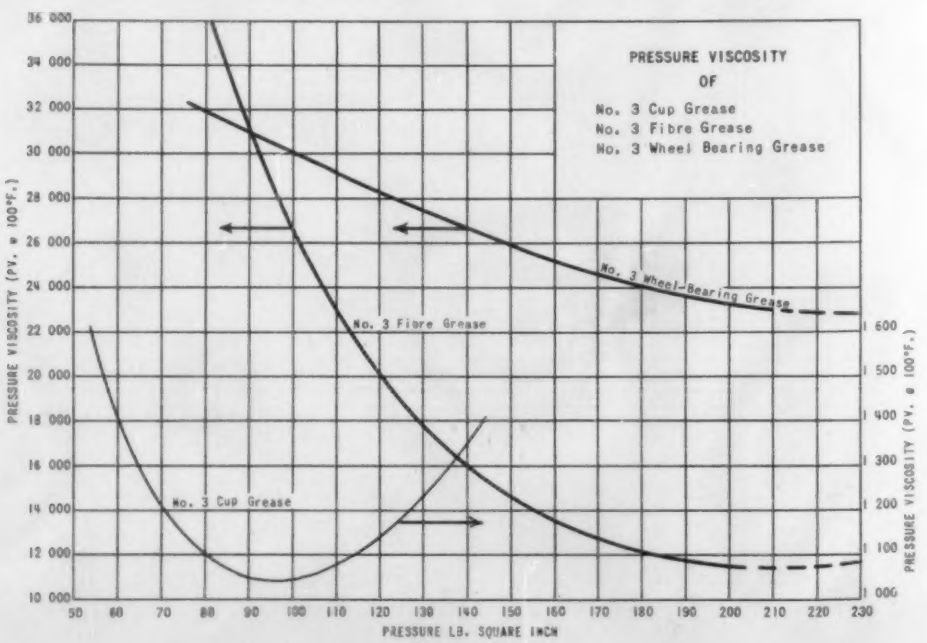

PRESSURE VISCOSITY OF
No. 3 Cup Grease
No. 3 Fibre Grease
No. 3 Wheel Bearing Grease
PRESSURE VISCOSITY (P.V. @ 100°F.)
PRESSURE LB. SQUARE INCH

FIGURE 7

The INSTITUTE SPOKESMAN

Published monthly by
THE NATIONAL LUBRICATING GREASE INSTITUTE

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498 Winspear Avenue, Buffalo, N. Y.

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Calumets' New Servolube Container Meets Real Need

With the decrease in cans and drums there is great need for a refillable can. Calumet Refining Company, Chicago, Ill. at the State Jobbers' Conventions created considerable excitement by the display of their new Servolube container, made of 20 gauge metal painted grey with tamper proof sealing lugs and faucet. This Servolube container will not stand reshipping, but it does make an ideal dispenser for the Jobber serving a large farm trade where storage of bulk oil in different grades is a problem. This is also a very handy device for service station use.

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Lubricating Oils — Greases
Foundry Core Oils

(Continued from Page 1)

that a different pressure viscosity (SUV seconds) is recorded (Figure 7). Since No. 3 cup and No. 3 fibre greases are made from the same viscosity oil (100 seconds viscosity at 100° F.) the pressure viscosity of No. 3 fibre grease is ten times higher and a higher pressure per square inch is recorded than for the No. 3 cup grease. The No. 3 wheel bearing grease (milled soda soap) made with a mineral cylinder stock has a minimum pressure viscosity which is more than double the other two greases of lower viscosity mineral oil.

When a semi-fluid grease was checked, it showed a pressure viscosity of 470 seconds SUV at 100° F. with only a pressure per square inch of 2½ pounds needed; the correct pressure for No. 3 cup grease was 95 pounds and for No. 3 fibre grease 230 pounds per square inch.

The A.S.T.M. cone, which has a total moving weight of 150 grams, is not practicable for numerical values higher than 385 or the N.L.G.I. No. 0 grade. To avoid the unreliability of very high penetration numbers, it is recommended that an aluminum cone and shaft be substituted, the dimensions to be the same as the standard A.S.T.M. cone but the total moving weight to be 50 grams. Figure 8 gives the conversion curves of the steel cone and the aluminum cone.

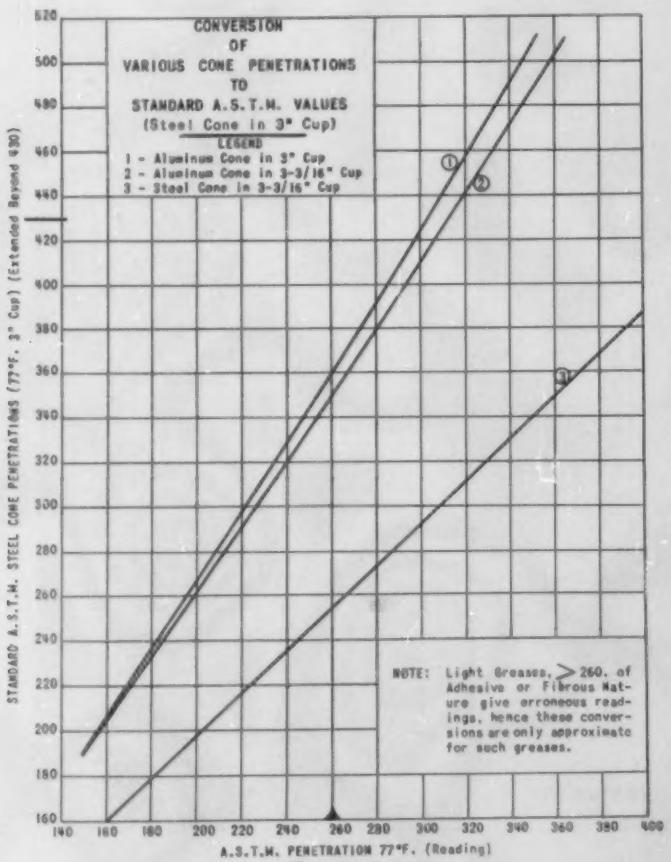

FIGURE 8

Research projects and the development of new products demand more precision than the cone penetrometer (A.S.T.M. Designation D217-38T) can ever be capable of; so, for extreme accuracy, the use of the Knopf Consadometer is recommended.

This Consadometer has been demonstrated and described in detail, by aid of lantern slides, at a meeting of the N.L.G.I.; also to committees of the A.S.T.M. and A.P.I. As this paper will not permit of a detailed discussion of the Consadometer and the many tests capable of being performed with this instrument, a very brief outline of its chief functions and particular features will be given.

The Consadometer is so named because it measures consistency, adhesiveness and other properties. By definition, the consistency of a grease is a measure of its resistance to deformation. The ideal consistency-instrument should read in force units; the plunger should be a disc (constant area) with slender stem (to avoid adhesion of material), the velocity of application should be uniform throughout each test and the same for all products; consistency values, whether obtained on small, intermediate or one pound samples should check each other within one per cent, on a uniform grease. The instrument should be capable of measuring other important properties.

Figure 9—*Consadometer* (on next page) —The turntable may be rotated at 22 rpm, or it may be made to rise at a uniform velocity, 9″ per minute, for all tests. Various types or sizes of plungers may be mounted in the clutch on the lower end of a shaft, whose vertical movement is restricted by four interchangeable calibrated springs, following the practice common with steam and gas engine indicators. The Consadometer has equal accuracy whether measuring a very light grease or a very heavy product, and the range is from 5 grams to 25,000 or a 5000:1 ratio.

Figure 10 — *P. D. Consistency* — A one pound can (3 3/16″ diameter is the standard container and the plunger head 1.3″ diameter. Note the two thermometers enabling temperature control within .2° F.

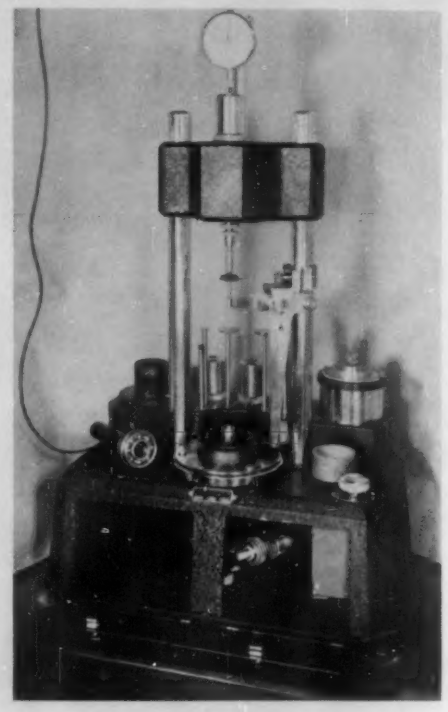

FIGURE 9

The P. D. consistency uses the basic principles; i. e., measuring accurately (within 0.2 to 1%) the force resisting the movement of a disc-plunger through the sample at a uniform velocity. The plunger has a flat head of such diameter that even light greases cannot come in contact with the ¼″ shank of the plunger during the test, thus preventing an adhesive drag.

With light grades, the conical surface of the A.S.T.M. cone, in contact with the lubricant, may be more than twice that involved, in which a ½″ spike-plunger is used; hence, light adhesive greases, tested by the A.S.T.M. cone method, may be in error over 50%; whereas light calcium products appear to be as much as 20% in error. These adhesiveness errors are eliminated in the P. D. consistency tests, but cannot be avoided in the cone test. The cone, therefore, measures a property which is a combination of consistency and adhesiveness, the

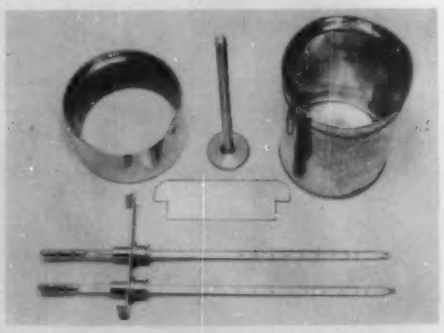

FIGURE 10

proportion of the latter to the former, being different for various types of grease. Since the exact error is undeterminable, we are unable to make corrections for adhesiveness. There are other errors involved in the cone method much more serious than the above, and fortunately something can be done about the matter.

Figure 11 is a correlation between Consadometer P. D. Consistency and A.S.T.M. Cone-Penetration plotted, respectively, as ordinate and abscissa, on an A.S.T.M. Kinematic Viscosity-Temperature chart "C". Dozens of tests were run on all types of greases having consistencies from 40 penetration to products as light as a No. 0000 grade. The plotted points, not shown on this plate, fell quite accurately on the lines of the original chart, up to a penetration of 260 with the 3" cup and to 270 with a one pound can (3 3/16" diameter). In other words, accurate correlation beyond these critical penetrations is impossible, since each type of grease follows along its individual line, making it almost impossible to know on just which line a penetration value should be plotted in order to determine its relative P. D. value.

The heavy line (1) is the locus of points furnished by cup-grease tests. It is made straight, which assumes there is no error involved in testing light cup-greases in a 3" mixer cup. However, actually there are small errors in such tests, but these will be ignored for the present.

The "fanning" of the dotted lines away from the cup-grease base-line (1) is chiefly due to the resistance offered by the grease to being extruded through the small annular orifice between cone and 3" cup wall. In the cross-sectional sketch of the cone and cup it is shown that the annular clearance for a 400 penetration is only about 5/16", whereas it should be at least 5 times this amount. To completely eliminate extrusion errors the clearance should be 7 times this amount, or 2½" between cone and 3" cup wall.

To be equally as free from extrusion error as the P. D. test the penetration should not exceed 260 in which case the clearance is over ⅞", or slightly greater than the penetration diameter of the cone. As mentioned above, a 400 penetration requires a 7" diameter container, even with light cup greases, if extrusion errors are to be eliminated.

Assume an adhesive, fibrous grease of 395 cone and 78 grams P. D. falling on "fan" line 3. This is about a No. 00 grade of No. 3 curve classification. Proceeding along the 78 gram P. D. line to the right, we intersect the base-line (1) at about 465 (extrapolated), being a value extended beyond 430, which is the total height of the cone. This indicates that the cone reading 395 is in error just 70 cone units. In other words, had a 10 pound pail been used instead of the 3" mixer cup, the cone would

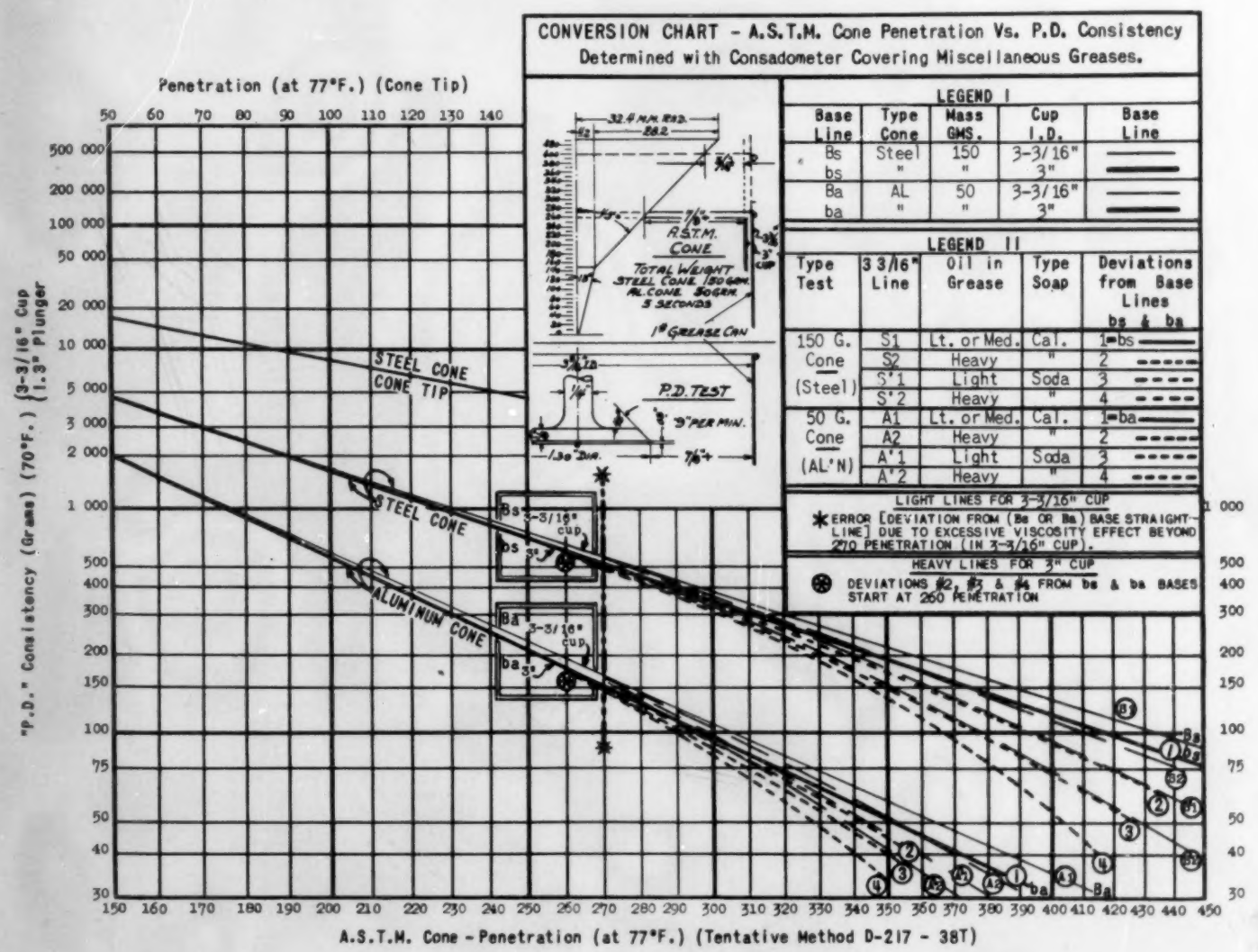
CONVERSION CHART - A.S.T.M. Cone Penetration Vs. P.D. Consistency
Determined with Consadometer Covering Miscellaneous Greases.
Penetration (at 77°F.) (Cone Tip)
"P.D." Consistency (Grams) (70°F.) (3-3/16" Cup (1.3" Plunger
A.S.T.M. Cone - Penetration (at 77°F.) (Tentative Method D-217 - 38T)
STEEL CONE
CONE TIP
STEEL CONE
ALUMINUM CONE
Bs 3-3/16" cup
bs 3"
Ba 3-3/16" cup
ba 3"
A.S.T.M. CONE
TOTAL WEIGHT STEEL CONE 150 GRS. AL. CONE 50 GRS. 5 SECONDS
1st GREASE CAN
P.D. TEST
3" PER MIN.
LEGEND I
Base Line | Type Cone | Mass GMS. | Cup I.D. | Base Line
Bs bs | Steel | 150 | 3-3/16" 3" |
Ba ba | AL | 50 | 3-3/16" 3" |
LEGEND II
Type Test | 3 3/16" Line | Oil in Grease | Type Soap | Deviations from Base Lines bs & ba
150 G. Cone (Steel) | S1 | Lt. or Med. | Cal. | 1=bs
S2 | Heavy | " | 2
S'1 | Light | Soda | 3
S'2 | Heavy | " | 4
50 G. Cone (AL'N) | A1 | Lt. or Med. | Cal. | 1=ba
A2 | Heavy | " | 2
A'1 | Light | Soda | 3
A'2 | Heavy | " | 4
LIGHT LINES FOR 3-3/16" CUP
* ERROR [DEVIATION FROM (Bs OR Ba) BASE STRAIGHT-LINE] DUE TO EXCESSIVE VISCOSITY EFFECT BEYOND 270 PENETRATION (IN 3-3/16" CUP).
HEAVY LINES FOR 3" CUP
DEVIATIONS #2, #3 & #4 FROM bs & ba BASES START AT 260 PENETRATION

Figure 11

have submerged completely for want of the extrusion resistant to stop it at 400.

Now proceed vertically along the 395 ordinate and note that it intersects the heavy base-line (1) at 125 grams, which is the "apparent" consistency, or the true P. D. Consistency of a cup grease having also a penetration of 395 (cone). This indicates an actual error of 61%, due to extrusion, adhesiveness and other causes. It might be pointed out here that if an error of 5 points (or less than 0.02") is made, because of carelessness in setting or because the 30° tip of the cone is not of correct length, then such a 5 point deviation represents an error of 8%. Also, the A.S.T.M. requests 5 determinations to be averaged for each grease, the mean deviation of which should not exceed 3 per cent. If the deviation is more than 3 per cent, a total of ten samples must be penetrated. It is pointed out above that a numerical percentage is meaningless and has little to do with actual errors. For example, in the case of the 395 grease discussed above, it is shown that a 3% numerical deviation is actually 18.5% error, or six times the apparent deviation. This is an admission that penetrations on several samples from the same pail may not check each other by 20 or 25 per cent.

A bearing grease, between a No. 1 and No. 2 grade of class 4, was tested. The penetration read 300 in the 3" cup and P.D. was 350 grams. Using the same methods as followed above, the test value of 300 should be expressed as 312 on the base-line (1); hence, the error in this case was 12 units. The 300 line followed vertically shows the apparent P.D. to be 350; hence, the actual error is 17% and much less than for the lighter product, because of the larger annular orifice. The 3% deviation mentioned by the A.S.T.M. is, in this case, only a trifle lower, being 13%.

A similar base-line and "fan" for the aluminum cup, as well as the correlation for the 30° tip range of the A.S.T.M. steel cone, shows that there is nothing but chaos beyond the "fan point" (260 penetration), and that errors are surprisingly much greater than has generally been believed.

There are many errors and inconveniences associated with the A.S.T.M. cone penetrometer, and since its scale is entirely arbitrary, it would be quite impossible to produce a worthwhile correlation between aluminum and steel cone readings, or the latter with tip readings. Also, it would be impossible to determine just how truthfully the cone penetrometer measured consistency, unless it were to be calibrated against some outside source. The standardizing instrument should not only be basically correct in principle so as to measure true consistency, but it must also be extremely accurate.

The P.D.-A.S.T.M. Cone points plot very satisfactorily along the three diagonal lines, down to 260 penetration, but beyond which penetration extrusion errors occur with all products except cup greases. To avoid, to a great extent, the errors due to "fanning", keep to the left of the arrows

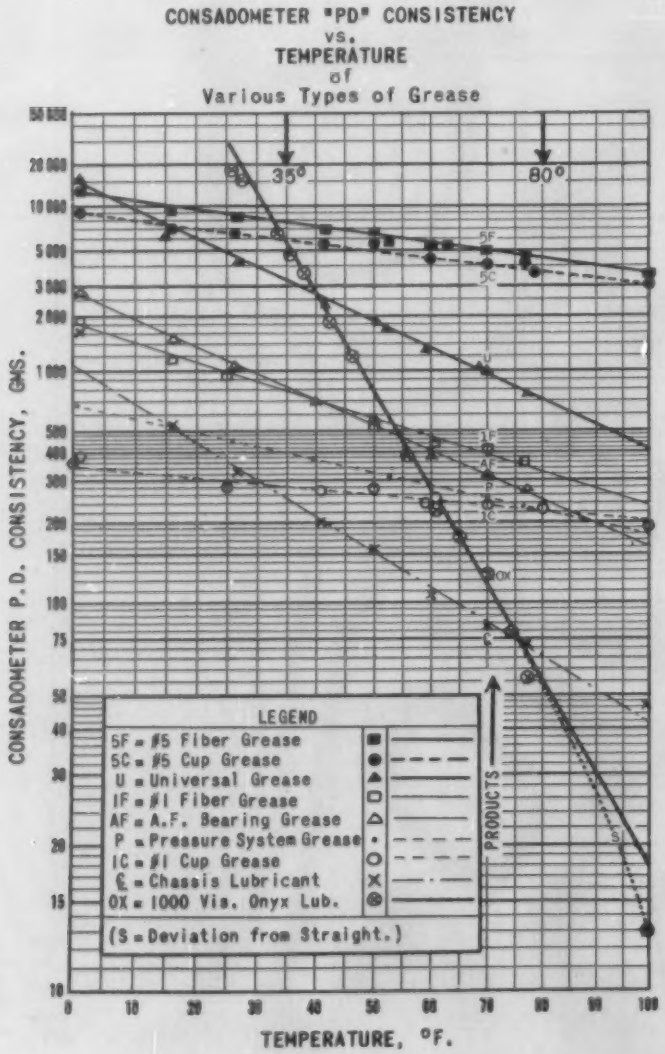

FIGURE 12

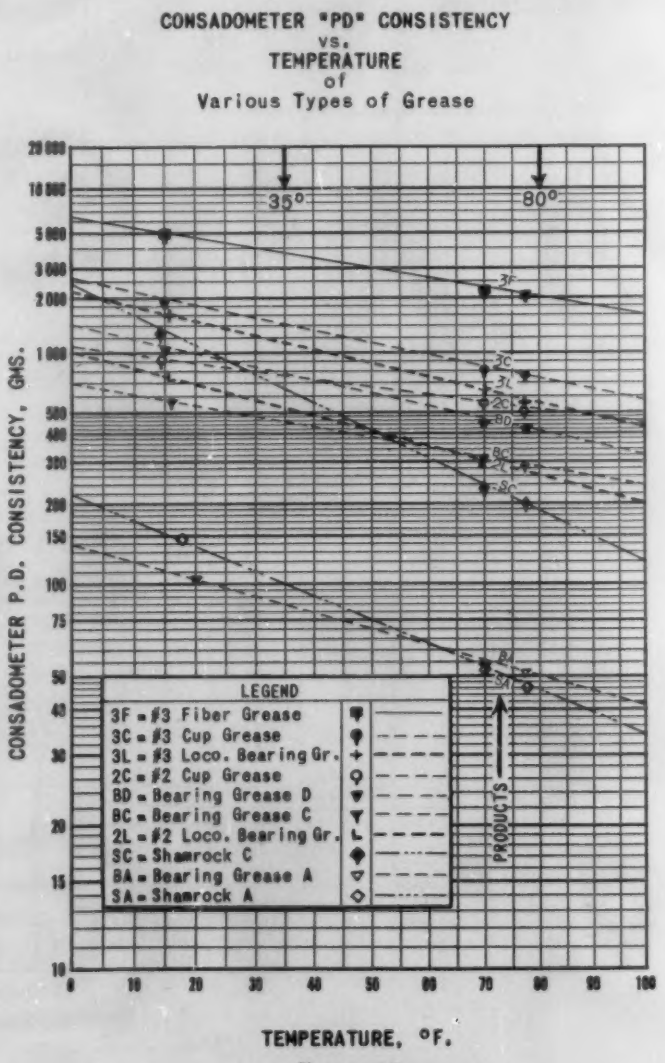

FIGURE 13

by the use of the aluminum cone whenever possible. This is good policy anyway, since the smaller the depth of penetration, the lower will be the error due to adhesiveness. Cylinder-stock greases, in particular, fall to the left of the diagonal, but there is no way to correct for this error, unless it is to use the P.D. plunger with slender stem.

It is quite well known that the viscosity index of an oil indicates the rate of change in viscosity from its viscosities at 100 and 210° F. (A.S.T.M. Designation D567-40T). This system arbitrarily takes Gulf Coast oil as zero index and typical Pennsylvania oils as 100. The index of a test oil is computed on a proportional basis of Saybolt readings of the zero and 100 index oils, as well as that of the test oil.

Figures 12 and 13 show how temperature affects the consistencies of 18 greases of various types and grades. About 8 readings from 0° F. to 100° F. were plotted for each sample producing straight lines on the A.S.T.M. "C" chart.

Note that No. 1 cup grease (1C) has a line that is almost horizontal, which is also true of other grades of cup grease. A grease unaffected by temperature change would plot horizontal. This is taken arbitrarily as 100 index. The heavy diagonal line OX represents a 1,000 viscosity at 210° F. asphaltic oil (no soap), the consistencies being 5,000 and 50 grams P.D. at 35° and 80° F., respectively, or 100 to 1 ratio. This slope is taken arbitrarily as zero index.

It is common practice to classify products by geometric progression: for example, SAE viscosity numbers for gear lubricants have been specified as 800, 1,500, 3,000, 6,000 viscosity (100° F.) and N.L.G.I. numbers converted to P.D. true consistency. Such P.D. values approximately span uniform distances on the chart. Various stations, such as 10,000, 5,000, 2,500, 1,200, 600, etc., etc., are selected for the bases of 9 triangles with bases from 35° to 80° F. The altitudes are all variable in measured distance, but the ratio of the higher reading to the base line reading is always 100:1. These "fan" lines, all representing DCI 100:1 oils, or zero DC index products, converge at a point near the upper left hand margin.

Dean and Davis define a 50 index oil as one having half the numerical difference between base and altitude viscosities. This point may divide the altitude into 15 and 85 per cent of the measured altitude. The DCI method defines the middle of the altitude as a 50 index; and ¼ distance from the base as 75 index.

This is the method used by the highway engineer in designating grades. A 10% grade is a 20 foot rise in the same distance.

Figure 14 is a log-log chart by the means of which consistency index may be determined if the P.D. consistencies at 35° and at 80° F. are known. The index may be checked with a half index-number, which also checks the index obtained by means of the protractor shown in Figure 15.

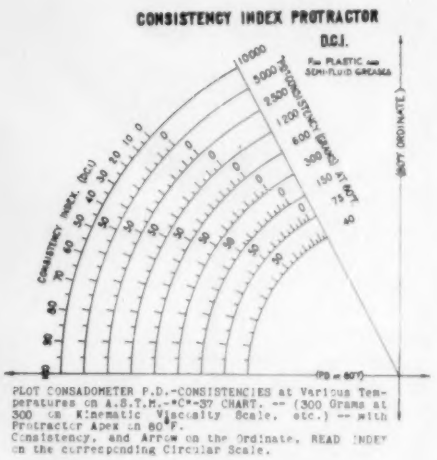
CONSISTENCY INDEX PROTRACTOR
D.C.I.
For PLASTIC and SEMI-FLUID GREASES
P.D. CONSISTENCY (GRAMS) AT 80°F.
CONSISTENCY INDEX (D.C.I.)
PD = 80°F.
PLOT CONSADOMETER P.D.-CONSISTENCIES at Various Temperatures on A.S.T.M.-"C"-37 CHART. -- (300 Grams at 300 on Kinematic Viscosity Scale, etc.) -- with Protractor Apex on 80°F.
Consistency, and Arrow on the Ordinate, READ INDEX on the corresponding Circular Scale.

Figure 15

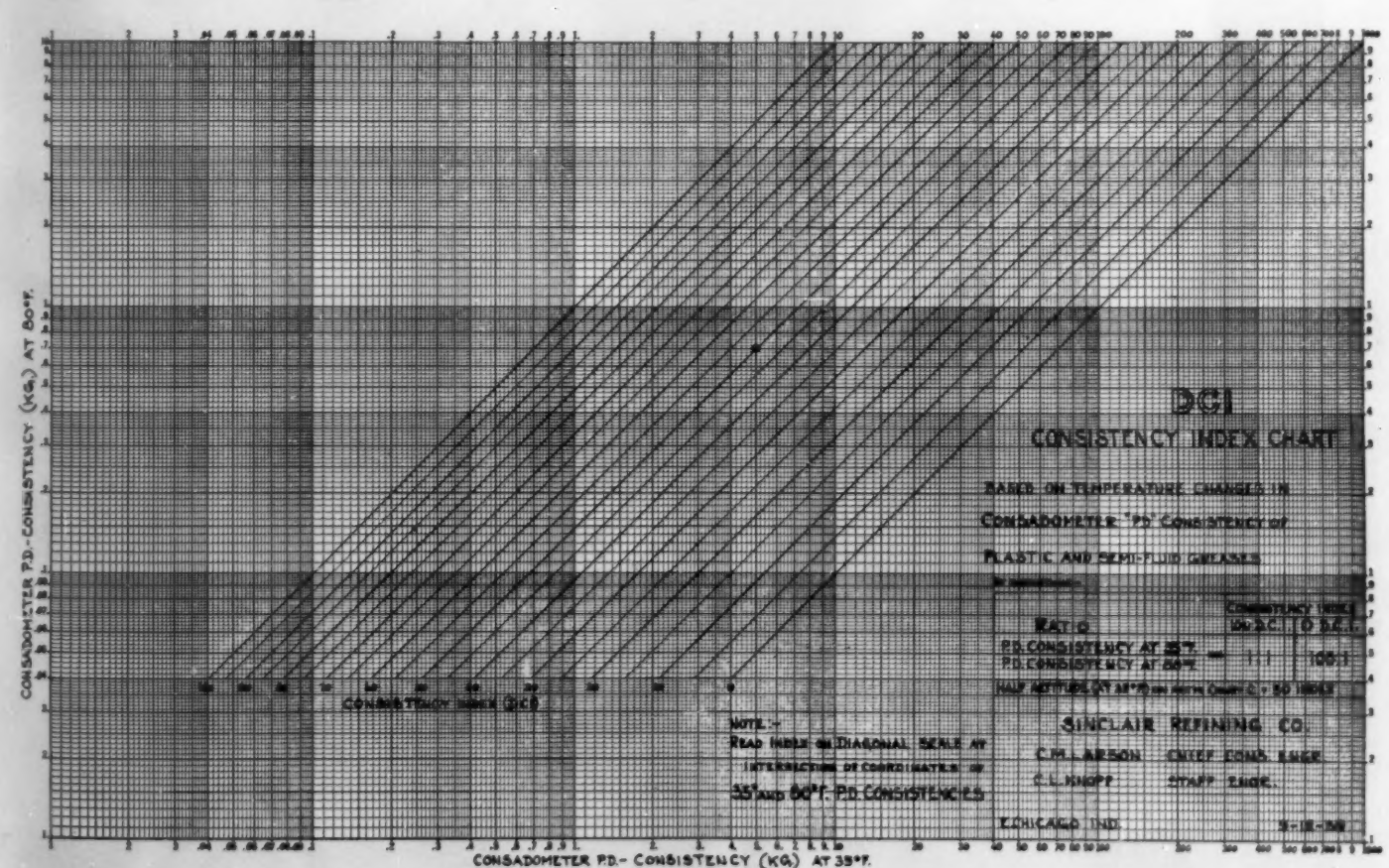

Figure 14

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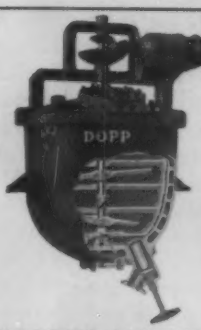
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